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DEVELOPMENT OF NEW TECHNOLOGIES FOR MINIMIZATION OF NUTRIENT EXCRETION LOSSES AND ODOURS IN SWINE MANURE

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Development of new technologies for minimization of nutrient excretion losses and odours in swine manure.

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Abstract/Summary

Two experiments were conducted during 1998-99 and 1999-00 at the Brandon Research Centre to determine the feasibility of omitting some amino acids (threonine, methionine or tryptophan) in replacing soybean meal in hulless-barley (HB) or covered-barley (CB) diets for reduction of nitrogen (N) excretion in swine manure while maintaining the performance of lean genotype pigs. A total of 160 lean genotype crossbred barrows and gilts were used in each of the two experiments. The five experimental grower (20 to 60 kg) and finisher diets (60 to 105 kg market weight) used in both experiments were: 1) HB or CB diets with no amino acid supplementation as control, 2) same as diets 1 supplemented with 1998 NAS-NRC recommended levels of amino acids lysine, threonine, methionine and tryptophan, 3) same as diets 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan according to ideal-protein amino acid ratios, 4) same as diets 3 with supplemental lysine and methionine but no threonine and tryptophan, and 5) same as diets 3 with supplemental lysine but no threonine, methionine and tryptophan. All diets were fed as pellets ad libitum with free access to drinking water. In Experiment 1 (HB diets) the average daily gain (ADG) was superior for diet 2 and 3 compared to diet 1, and the ADG was inferior for diets 4 and 5 compared to diet 3 during the grower period. The feed conversion efficiency was superior for all amino acid supplemented diets 2, 3, 4 and 5 compared to diet 1 during both grower and finisher periods. The carcass index was superior in pigs fed diets 2 compared to other diets. The reduction of N excretion in manure was 34.0, 32.0 and 30.2 % by feeding diets 3, 4, and5, respectively compared to diet 2 during the grower period but this reduction was only 4.3, 9.8, and 2.3 %, respectively during the finisher period. In Experiment 2 (CB diets), the ADG was higher ($P < 0.05$) for diet 2 compared to diet 1 during the grower and finisher periods. Feeding diets 4 and 5 reduced ($P < 0.05$) the ADG and feed conversion efficiency during both grower and finisher periods. The carcass index was similar among the diets. The reduction of N excretion in manure was 34.7, 10.9 and 7.5 % by feeding diets 3, 4, and5, respectively compared to diet 2 during the grower period, and this reduction was 16.7, 22.9, and 22.4 %, respectively during the finisher period. The overall results indicated that omitting threonine, methionine and tryptophan for replacing soybean meal reduced N excretion in swine manure but it also reduced the pig performance more in CB compared to HB diets. An economic evaluation indicated that omitting of amino acids, threonine, methionine or tryptophan for relacing soybean meal to reduce manure N excretion may be feasible in HB diets but it is not economical in CB diets because of severe growth depression caused by feeding such diets.

Key words: Pigs, amino acids, Hulless-barley, covered-barley nitrogen, swine manure.

Executive Summary

This study was initiated to determine the feasibility of omitting some supplemental amino acids (threonine, methionine, and tryptophan) for replacing protein supplements (soybean meal) in hulless-barley (HB) or covered-barley (CB) diets to reduce nitrogen (N) excretion in swine manure while maintaining performance of lean genotype pigs. A total of 160 lean genotype barrows and gilts purchased from a commercial source were used in each of the two experiments. They were housed, sexes separate, in a total confinement heated building at the rate of 4 pigs per pen. The five experimental grower (20 to 60 kg) and finisher diets (60 to 105 kg market weight) used were: 1) HB or CB diets with no amino acid supplementation as control, 2) same as diet 1 with supplemental amino acids lysine, threonine, methionine and tryptophan at NAS-NRC (1998) recommended levels, 3) same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan according to ideal-protein amino acid ratios, 4) same as diet 3 with supplemental lysine and methionine but no threonine and tryptophan, and 5) same as diet 3 with supplemental lysine but no threonine, methionine and tryptophan. All diets were steam pelleted, and fed ad libitum in self-feeders with free access to drinking water. All pigs were probed (ultrasonic) for backfat thickness, and shipped at about 105 kg body weight to a local abattoir for slaughter and evaluation of carcass quality (value Index and percent yield).

Nutrient balance studies were conducted during both the grower and finisher periods. A total of 20 gilts, 4 from each of 5 treatment groups were used during each period in both the experiments. During the grower period, gilts weighing about 37 kg were transferred from pens into the grower metabolism crates equipped with a mesh screen underneath to collect feces and a special sloped bottom tray to collect urine. During the finishing period, gilts weighing about 95 kg were transferred into finisher metabolism crates equipped with perforated plastic flooring and bottom trays to collect total feces. Foley catheters were inserted through the urethra into the urinary bladder of gilts for total collection of urine. They were individually fed with a measured amount of respective treatment diets, and the remaining amount of feed in the feed troughs at the end of each 24 h period was weighed back to monitor the daily feed consumption. A total collection of feces and urine was made for four 24 h periods. The dry matter and nitrogen content of feed, feces and urine were determined, and the average daily intake of dry matter and nitrogen from feed, and their average daily excretion in feces and urine for each gilt were calculated.

The results indicated that, in Experiment 1, feeding HB diets 2 and 3 improved the growth rate and feed conversion efficiency compared to diet 1 during both grower and finisher periods. Feeding diets 4 and 5 reduced the ADG by about 16 % compared to diet 3 during the grower but not during the finisher period indicating that removal of threonine, methionine or tryptophan was detrimental only during the grower period. The carcass index was superior in pigs fed diet 3 compared to other diets. The reduction of N excretion in manure was 34.0, 32.0 and 30.2 % by feeding diets 3, 4, and5, respectively compared to diet 2 during the grower period but this reduction was only 4.3, 9.8, and 2.3 %, respectively during the finisher period. In Experiment 2, feeding CB diets 2 improved the ADG compared to diet 1 during the grower but not finisher period. Feeding diets 4 and 5 severely reduced the ADG and feed conversion

efficiency compared to diet 3 during both grower and finisher periods. Carcass value index was similar among the diets. The reduction of N excretion in manure was 34.7, 10.9 and 7.5 % by feeding diets 3, 4, and5, respectively compared to diet 2 during the grower period, and this reduction was 16.7, 22.9, and 22.4 %, respectively during the finisher period. The overall results indicated that omitting threonine, methionine and tryptophan for replacing soybean meal reduced N excretion in swine manure but it also reduced the growth performance, more reduction in CB compared to HB diets. An economic evaluation of the extra cost of adding amino acids indicated that omitting amino acids, threonine, methionine or tryptophan to replace soybean meal in HB diets

Technical Report

a) Background

A sustainable swine production system is defined as the one that combines production and management techniques to enhance profit and improve the ecological and socioeconomic surroundings (Honeyman, 1996). However, the zeal for economic benefits often results in production practices that are out of balance with the environment. The abolition of grain transportation subsidies, and a need for value added economy in addition to an increasing demand for quality pork in world markets made the way for a rapid expansion of swine production in western Canada. The major environmental concerns of such increase in swine production are about the potential water pollution by manure nutrients mainly nitrogen and phosphorus, and objectionable odours associated with swine manure. Leaching of excess ammonia-nitrogen and nitrates into the waterways from manure storage or heavily fertilized soils is harmful to human health, fish and aquatic ecosystems. Atmospheric ammonia may combine with nitrates and sulfates from industrial emissions to form aerosols of ammonium nitrate and ammonium sulphate which can adversely affect human health. Zebarth et al. (1997) reported that the degree of animal intensification was the primary factor which determines the potential for nitrogen leaching into surface and ground water resources. Odours generated from swine buildings, swine manure storage lagoons, and manure spreading is becoming a great concern in both rural and urban areas. Therefore, the future of swine production and associated economic growth in western Canada depend on resolving these problems.

In some European countries, quotas were imposed on how much nitrogen and phosphorus can be generated and used on livestock farms (Jongbloed and Lenis, 1997 and Bruchem and Tamminga, 1997). Although such enforcement of quotas may not occur in western Canada in the near future because of large farm land available for manure application, the long distance transportation of manure is not practical or economical. The new provincial environmental regulations require preparation of nutrient management plans for large swine operations. It is, therefore, necessary to develop effective nutrient management technologies and guidelines to reduce nutrient excretion losses in swine manure for sustainable swine production and to minimize adverse effects on the environment.

Leneman et al. (1993) concluded that nutrient management of nitrogen and phosphorus

in swine diets is the most cost effective way of reducing their overall impact on the environment. Traditionally the feed industry and swine producers have ignored the environmental impact of diet formulation because the main goal was to achieve maximum performance with high nutrient density diets. This trend needs to be altered in favour of environmentally compatible feeding programs to minimize the nutrient excretion losses in swine manure. The NAS-NRC (1998) devoted a separate chapter to emphasize the importance of minimizing nutrient excretion losses. The nutritional strategies for reduction of nutrient excretion losses in swine manure include 1) an accurate prediction of bioavailability of nutrients in feedstuffs, 2) more accurate definition of nutrient requirements at various stages of growth and physiological states, 3) reduction of safety margin allowances of nutrients in feed formulation, 4) accurate supplementation of nutrients to correct imbalances in diets, and 5) improving digestibility of feedstuffs by supplementation with enzymes and bioadditives.

Lee and Kay (1997) reported that reduced dietary crude protein decreased the water intake by pigs resulting in approximately 30.0 % lower water and slurry handling costs. Gatel and Grosjean (1992) reported that reduction of dietary protein decreased nitrogen excretion by about 20.0 % in swine manure. However, a reduction of dietary protein without consideration to the amino acid requirements can adversely affect the pig growth performance and carcass quality of modern lean genotype pigs. Lenis (1989) reported that reducing dietary protein by 2.0 %, and supplementing with synthetic amino acids reduced nitrogen excretion by about 25.0 % in swine manure.

The ideal-protein concept where the dietary amino acids are provided in required ratios was first proposed by ARC (1981), and is now widely adapted by the feed industry in formulation of swine diets. Kerr and Easter (1995) reported that feeding low protein (12.0 vs 16.0%) corn-soybean meal diets supplemented with amino acids, lysine, threonine and tryptophan reduced nitrogen excretion by about 30.0 % in grower pigs without affecting the growth performance. However, the reduction of nitrogen excretion was only 10.0 % with low protein diets without amino acid supplementation. Tuitoek et al (1997) reported that dietary crude protein levels from corn-soybean meal based diets can be reduced by 22.0 % without affecting the grower pig (20 to 55 kg live weight) performance if lysine and other amino acid levels are kept close to the requirement. Hulless barley is now widely used in western Canada in swine and poultry diets because of its relatively high energy and protein content. Also a low fraction of hulls in hulless barley can reduce the volume of faecal dry matter output. Grandhi and Baidoo (1997) reported that the nutritive value of hulless barley can be improved in diets by amino acid supplementation for grower-finisher pigs. Grandhi (1998) also reported that feeding hulless barley diets during grower and finisher period reduced the fecal dry matter output by about 25.0 % compared to covered barley diets, and replacing soybean meal with amino acids lysine, threonine, methionine and tryptophan according to an ideal-protein amino acid ratio basis reduced the nitrogen excretion by about 28.0 % in swine manure. A reduction of nitrogen excretion in swine manure achieved by modification of hulless barley diets can decrease the amount of land base required for manure disposal. However, the cost of some synthetic amino acids (eg. threonine and tryptophan) is relatively high at the present time, and it may not be economical to include higher levels of these amino acids in diets to replace all soybean meal in corn-soybean meal based diets. In hulless barley-soybean meal based diets, it may be more

economical to replace soybean meal with supplemental amino acids because of a relatively high protein level in hulless barley, and low amount of supplemental amino acids required, however, this may be different in covered barley based diets.

b) Objectives

To develop precision feeding programs based on hulless or covered barley diets with optimum protein and amino acid levels to minimize the nitrogen excretion loss and odours in swine manure while maintaining the optimum growth performance and carcass quality. The effects of omitting some supplemental amino acids for replacing soybean meal in hulless or covered barley diets on growth performance, carcass quality and nitrogen excretion were determined.

c) Materials and methods

Two experiments were conducted, using hulless or covered barley based diets.. First experiment was conducted from October 1998 to March 1999, using hulless barley (HB) based diets. The second experiment was conducted from July 1999 to January 2000, using covered barley (CB) diets. A total of 160 lean genotype crossbred barrows and gilts purchased from a commercial source were used in each of the two experiment. Pigs were brought in at about 15.0 kg body weight, and were housed in a total confinement heated building, sexes separate, at the rate of 4 pigs per pen. They were fed an 18% protein starter diet until they were assigned to experimental grower diets at about 20.0 kg pen average body weight. The five experimental grower and finisher diets (Tables 1 and 2) used were: 1) HB or CB diets with no amino acid supplementation as control, 2) same as diet 1 with supplemental amino acids lysine, threonine, methionine and tryptophan according to NAS-NRC (1998) recommended levels, 3) same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan according to ideal-protein amino acid ratios, 4) same as diet 3 with no supplemental threonine and tryptophan, and 5) same as diets 3 with no supplemental threonine, methionine and tryptophan. The vitamin-trace mineral premixes including synthetic amino acids were mixed at the Brandon Research Centre, and supplied to a local feed mill to mix in the diets. All diets were steam pelleted, and fed in self-feeders with free access to drinking water. Pigs were fed the experimental grower diets from 20 to 60 kg pen average body weight and then switched to experimental finisher diets at about 60.0 kg pen average body weight. The pig weights and pen average feed consumption were recorded on biweekly basis. Blood samples were colleted from conjunctival sinus during the finishing period for determining plasma urea nitrogen. All pigs were probed (ultrasonic) for backfat thickness, and shipped at about 105.0 kg body weight to a local abattoir for slaughter and evaluation of carcass merit (value Index and percent yield).

Nutrient balance studies

Nutrient balance studies were conducted during both the grower and finisher periods. A total of 20 gilts, 4 from each of 5 treatment groups were used during each period. During the grower period, gilts weighing about 37 kg were transferred from pens into the grower metabolism crates equipped with a mesh screen underneath to collect feces and a special sloped

bottom tray to collect urine. Gilts were housed in these crates about 72 h prior to the collection of feces and urine for acclimatization. They were individually fed with a measured amount of respective treatment grower diets, and the remaining amount of feed in the feed troughs at the end of each 24 h period was weighed back to calculate the daily feed consumption. A total collection of feces and urine was made for each of the four 24 h periods, and the gilts were returned to their respective pens. During the finisher period, gilts weighing about 95 kg were transferred into large metabolism crates about 72 h prior to starting the collection of faces and urine for acclimatization. These crates were equipped with perforated plastic flooring and bottom trays to collect total feces. Foley catheters were inserted through the urethra into the urinary bladder of gilts for collection of total urine. They were individually fed with a measured amount of respective treatment finisher diets, and the remaining amount of feed in the feed troughs at the end of each 24 h period was weighed back to calculate the daily feed consumption. A total collection of feces and urine was made for each of the four 24 h periods, and the gilts were shipped to the market.

After measuring each 24 h period total output, an aliquot samples of feces and urine were collected from each gilt and frozen. At the end of four 24 h periods, the samples were thawed and pooled for each gilt. The pooled samples were thoroughly mixed, and a representative sample from the pooled sample was frozen for further analysis. The dry matter in feces and urine were determined after freeze-drying. The nitrogen content of feed, feces and urine were determined using Kjeltec system according to the methods of Association Of Analytical Chemists (1990). The average daily intake of dry matter and nitrogen from feed, and their average daily excretion in feces and urine for each gilt were determined.

d) observations/results

The amino acid analysis of experimental diets indicated that the supplemental amino acid concentrations and ratios were close to the intended levels in both experiments (Tables 3 and 4).

1. Experiment 1 (Hulless-barley diets)

i) Growth performance

The average daily gains (ADG) during the grower period (~20 to 60 kg) were not different among the diets (Table 5). However, pigs fed diets 2 and 3 had superior ($P = 0.07$) ADG compared to diet 1 indicating that supplemental amino acids lysine, threonine, methionine and tryptophan according to an ideal-protein amino acid ratios in diets 2 and 3 optimized the growth performance in both barrows and gilts. A complete replacement of soybean meal protein supplement in diet 3 with amino acids lysine, threonine, methionine and tryptophan maintained the ADG and feed to gain ratios similar to diet 2 indicating that the protein supplement in HB diets can be replaced with supplemental amino acids with no adverse effect on growth performance. However, when supplemental threonine and tryptophan were omitted in diet 4, and also omitting of supplemental threonine, tryptophan and methionine in diet 5 reduced the ADG compared to diet 3 in both barrows and gilts indicating that all the above four supplemental amino acids are required to effectively replace the soybean meal protein supplement in grower

diets. During the finisher period (60 kg to market weight), the ADG was superior in all amino acid supplemented diets 2 to 5 compared to diet 1. Omitting of supplemental threonine and tryptophan in diet 4 or threonine, tryptophan and methionine in diet 5 did not reduce the growth rate and feed conversion efficiency during the finisher period unlike during the grower period indicating that dietary amino acid balance in HB diets during the finisher period may not be critical for growth rate. This was in agreement with our previous observations (Grandhi and Baidoo 1997) where the amino acid supplementation to HB diets improved the growth rate during the grower but not during the finisher period. The overall ADG was also superior for diets 2 and 3 compared to diets 1, 4, and 5 in both barrows and gilts. The feed to gain ratios were lower ($P < 0.01$) in pigs fed diets 2 and 3 compared to diet 1, and omitting some amino acids in diets 4 and 5 increased ($P < 0.01$) the feed to gain ratios indicating that dietary amino acid balance is critical for feed conversion efficiency. During the finisher period, the feed to gain ratios were lower ($P < 0.01$) for all the amino acid supplemented diets 2 to 5 compared to diet 1 indicating an improved feed conversion efficiency. Omitting of amino acids did not increase the feed to gain ratios during the finisher period. The overall feed to gain ratios were also lower for all amino acid supplemented diets 2 to 5 compared to diet 1.

ii) Carcass quality

The P2 backfat thickness adjusted to 100 kg body weight was not different ($P > 0.05$) among the diets. Gilts had a relatively lower back fat thickness compared to barrows. The carcass index values were higher ($P < 0.03$) for pigs fed diet 3 compared to other diets indicating that higher amino acid levels increased the carcass leanness. The percent carcass yield was also not significantly different ($P > 0.05$) among the diets The plasma urea nitrogen values were lower ($P < 0.01$) for amino acid supplemented diets compared to diet 1 indicating an improved nitrogen metabolism in these pigs.

iii) Nutrient metabolism and excretion

During the grower period, the apparent digestibility and retention of dry matter and energy were not significantly different ($P > 0.05$) among the diets (Table 6). The apparent nitrogen retention was higher ($P = 0.01$) for diets 2 to 5 compared to diet 1. Pigs fed diet 2 reduced the nitrogen excretion by 17.0 % compared to diet 1. Replacing soybean meal protein supplement with supplemental amino acids in diet 3 reduced the nitrogen excretion by 33.8 % compared to diet 2. Omitting amino acids threonine and tryptophan or threonine, tryptophan and methionine in diets 4 and 5 reduced nitrogen excretion by 32.0 and 30.2 % respectively compared to diet 2. During the finisher period, the apparent digestibility and retention of dry matter, energy and nitrogen were not significantly different among the diets. The reduction of nitrogen excretion in manure was relatively lower for diets 3, 4 and 5 compared to diet 2. This was probably because of a relatively smaller difference in nitrogen intake between finisher diets 2, 3, 4 and 5, and a lower level of amino acid supplementation required for replacing soybean meal in finisher diets. A similar decrease in N excretion was also observed in another study where the soybean meal was replaced by amino acids in HB diets (Grandhi 2000)

2. Experiment 2 (Covered-barley diets)

i) Growth performance

The ADG was higher ($P < 0.01$) for diet 2 compared to diet 1 indicating that supplemental amino acids lysine, threonine, methionine and tryptophan according to an ideal-protein amino acid ratios in diet 2 optimized the growth rate in both barrows and gilts (Table 7). The ADG was lower for diet 3 compared to diets 1 and 2 indicating that complete replacement of soybean meal in CB diet with amino acids lysine, threonine, methionine and tryptophan could not maintain the ADG at an optimal level. Omitting of supplemental threonine and tryptophan in diet 4 or threonine, tryptophan and methionine in diet 5 reduced ($P < 0.01$) the ADG compared to diet 3 in both barrows and gilts indicating that all the four supplemental amino acids including lysine are required to effectively replace the soybean meal in grower diets. During the finisher period (60 kg to market weight), the ADG was higher in diet 2 compared to diet 1. Omitting of supplemental threonine and tryptophan in diet 4 or threonine, tryptophan and methionine in diet 5 reduced the ADG compared to diet 3 similar to that observed during the grower period. This was a different response than that observed in HB diets. The feed to gain ratios were lower ($P < 0.01$) for pigs fed diet 2 compared to diet 1, and omitting threonine and tryptophan in diet 4 or omitting threonine, tryptophan and methionine in diet 5 increased ($P < 0.01$) the feed to gain ratios compared to diet 3 indicating that dietary amino acid balance is critical for feed conversion efficiency during the grower period. During the finisher period also, the feed to gain ratios were higher for diets 4 and 5 compared to diet 3.

ii) Carcass quality

The P2 backfat thickness adjusted to 100 kg body weight was not significantly different among the diets. Gilts had a relatively lower back fat thickness compared to barrows. The carcass index values were superior for diet 2 compared to other diets indicating that higher amino acid levels increased the carcass leanness in both barrows and gilts. The percent carcass yield was also not significantly different among the diets. The plasma urea nitrogen values were lower ($P < 0.01$) for amino acid supplemented diets compared to diet 1 in both barrows and gilts indicating an improved nitrogen metabolism in these pigs. Omitting threonine, methionine and tryptophan increased the plasma urea nitrogen indicating an inefficient utilization of nitrogen due to amino acid imbalance.

iii) Nutrient metabolism and excretion

During the grower period, the apparent digestibility and retention of dry matter and energy were not significantly different ($P > 0.05$) among the diets (Table 8). The apparent nitrogen retention was higher ($P = 0.04$) for diets 2 and 3 compared to diet 1, 4 and 5. Pigs fed diet 2 had reduced nitrogen excretion by 21.1 % compared to diet 1. Replacing soybean meal protein supplement with supplemental amino acids in diet 3 reduced the nitrogen excretion by 34.7 % compared to diet 2. Omitting amino acids threonine and tryptophan or threonine, tryptophan and methionine in diets 4 and 5 reduced the nitrogen excretion by 10.9 and 7.5 % respectively compared to diet 2. During the finisher period, the apparent digestibility and

retention of dry matter and energy were lower for diet 2 compared to diet 1, and the reason for this was not known. The nitrogen retention was superior for diets 3, 4 an 5 compared to diets 1 and 2 similar to that observed during the grower period. Feeding diets 3, 4 and 5 reduced the nitrogen excretion by 49.7, 31.0 and 32.5% respectively compared to diet 2.

iv) Ammonia in stored manure

In hulless-barley diets (experiment 1), the ammonia concentration in stored liquid manure was lower ($P < 0.05$) for diet 4 compared to diet 1 but it was not different among the other diets (Table 9). In covered-barley diets (experiment 2), the ammonia concentration was lower for diets 3, 4 and 5 compared to diets 1 and 2. It was also lower for diets 4 and 5 compared to diet 3. The ammonia concentrations were relatively lower for CB compared to HB diets.

v) Economic evaluation

In experiment 1 with HB diets, the cost of adding all amino acids, lysine, threonine, methionine and tryptophan to diet 2 according to NAS-NRC (1998) recommended levels was about $7.54 per pig, and this cost increased to $12.98 per pig for diet 3 where the soybean meal was replaced by additional amino acids (Table 10). When threonine and tryptophan were omitted in diet 4, the cost came down to $6.30, and when threonine, methionine and tryptophan were omitted in diet 5, the cost came down to $5.83. When the improvement (or decrease) of ADG and carcass quality was taken into consideration then the net cost of amino acids was $7.88, $6.60 and $5.22, respectively for diets 3, 4 and 5. The reduction of manure N excretion was similar among the diets 3, 4 and 5 indicating that the amino acids threonine, methionine and tryptophan can be omitted for replacing soybean meal in HB diets with considerable savings in feed costs per pig, still achieve an optimal manure N reduction.

In experiment 2 with CB diets, the cost of adding amino acids are relatively higher in diets 3, 4 and 5 compared to HB diets in experiment 1. Omitting threonine, methionine or tryptophan in diets 4 and 5 lowered the feed costs per pig but it severely reduced the pig growth performance. When the decreased pig growth performance and carcass quality were taken into consideration, the net cost per pig was $25.39, $24.99 and $24.59, respectively for diets 3, 4 and 5. Although an optimal manure N reduction was achieved with diets 3, 4 and 5, this feeding strategy was not economical because of a resulting severe reduction in pig growth performance.

e) Conclusions

Supplementing HB or CB diets with amino acids lysine, threonine, methionine and tryptophan according to 1998 NAS-NRC recommended levels improved the growth rate and feed conversion efficiency of both barrows and gilts during the grower and finisher periods compared to control diet 1 indicating that lean genotype pigs with higher genetic potential for growth performance benefit by an optimum amino acid nutrition. However, when soybean was replaced by amino acids in diet 3, the growth rate was poor compared to diet 2 during the grower period, and this reduction in growth rate was more for CB diet compared to HB diet. These results

indicated that in CB diets, replacing soybean meal with amino acids did not maintain the growth performance similar to that observed with HB diets. Omitting amino acids threonine, methionine and tryptophan reduced the growth rate by about 17 % in HB diets compared to about 23.0 % in CB diets compared to diet 3 during the grower period. This reduction of growth rate was not observed during the finisher period in HB diets but it was about 18 % in CB diets compared to diet 3. The higher dietary amino acid levels in diet 2 reduced nitrogen excretion by 17.0 and 20.5 % for HB and CB diets, respectively during the grower period indicating an optimum nitrogen metabolism with amino acid supplementation. Replacing soybean meal with amino acids in both HB and CB diets further reduced nitrogen excretion in manure. Omitting threonine, methionine and tryptophan for replacing soybean meal maintained the reduction of nitrogen excretion in manure similar to diet 3 in both HB and CB diets. The overall results indicated that amino acids, threonine, methionine and tryptophan can be omitted for replacing soybean meal in HB diets for optimal reduction of nitrogen excretion with a minimum adverse effect on pig performance but this was not feasible or economical in CB diets because a severe reduction in growth performance by omitting those amino acids.

f) impact

These findings will provide the options to the swine producers and feed industry in making economic decisions for amino acid supplementation to HB or CB diets during grower and finisher periods to minimize the nitrogen excretion in swine manure without compromising the genetic potential for the growth performance and carcass quality of modern lean genotype pigs.

Transfer of technology:

1. A paper on "Economics of amino acid supplementation to hulless barley diets for reduction of nitrogen in swine manure" was presented at the 1999 Saskatchewan pork industry symposium held at Saskatoon during November 17-19, 1999.

2. A paper on "Dietary amino acids for optimum reduction of nitrogen excretion in swine manure" was presented at the Manure management 2000 meetings in Calgary, June 26-29, 2000.

3. A paper on "Supplemental amino acids for reduction of nitrogen in swine manure" was presented at the Agricultural Institute of Canada, Agri-Food 2000 conference in Winnipeg, MB, July 15-20, 2000.

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Preparation of a scientific manuscript is in progress for publication in the Canadian Journal of Animal science. It may take up to one year for the review process to complete, revisions made, galley proofs approved, and the manuscript in press.

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Personnel

Name	Position	Paid from
R.R. Grandhi, PhD., PAg.,	Research Scientist	A-Base budget
R.D. Westwood	Technician	A-Base budget
G.I. Turner	Research Assistant	Research grants
F. Willms	Herds person	MII funds & Research grants

N. Thiry	Summer student	Research grants

Equipment

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Table 1. Composition of Grower and Finisher diets in experiment 1 (Hulless-barley)

Ingredients (kg T^{-1}) Diet[z]:	Grower					Finisher				
	1	2	3	4	5	1	2	3	4	5
Hulless barley	877.2	885.6	961.4	965.1	965.1	936.5	943.2	968.8	971.1	971.4
Soyabean meal (48%)	97.5	82.0	Nil	Nil	Nil	40.0	27.5	Nil	Nil	Nil
Calcium carbonate	12.3	12.0	12.2	12.2	12.2	12.0	12.0	12.0	12.0	12.0
Monocal. phos.(18Ca21P)	7.5	8.0	9.0	9.0	9.0	6.0	6.4	6.5	6.5	6.5
Iodized salt	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Vit-Trace min. premix[y]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
L-Lysine Hcl (78%)	Nil	4.4	7.2	7.2	7.2	Nil	3.7	4.6	4.6	4.6
L-Threonine (98%)	Nil	2.0	3.3	Nil	Nil	Nil	1.5	2.2	Nil	Nil
DL-Methionine	Nil	0.5	1.0	1.0	Nil	Nil	0.2	0.3	0.3	Nil
L-Tryptophan	Nil	Nil	0.4	Nil	Nil	Nil	Nil	0.1	Nil	Nil
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Nutrient levels (Dry matter basis):										
Energy (MJ kg^{-1} DE)	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Crude protein (g kg^{-1})	177.8	177.8	151.1	151.1	151.1	155.5	155.5	147.8	147.8	147.8
Crude Fibre (g kg^{-1})	2.3	2.3	2.1	2.1	2.1	2.2	2.2	2.1	2.1	2.1
Crude fat (g kg^{-1})	2.5	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Calcium (g kg^{-1})	7.2	7.2	7.2	7.2	7.2	6.7	6.7	6.7	6.7	6.7
Phosphorus (g kg^{-1})	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1

[z] Diet: 1 = Hulless-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

[y] Supplied per kilogram of diet: vitamin A, 8,400 IU; vitamin D3, 840 IU, vitamin E, 30 IU; vitamin K, 2.5 mg; vitamin B_{12}, 18 mcg; riboflavin, 3.6 mg; niacin, 19.8 mg; D-pantothenic acid, 9.7 mg; choline 115 mg; iron, 84 mg; zinc, 150 mg; manganese, 24 mg; copper, 120 mg; iodine, 0.3 mg and selenium, 0.36 mg.

Table 2. Composition of Grower and Finisher diets in experiment 2 (Covered-barley)

Ingredients (kg T^{-1}) Diet[z]:	Grower					Finisher				
	1	2	3	4	5	1	2	3	4	5
Covered-barley	809.0	813.0	930.7	934.8	936.1	854.5	866.3	935.0	937.5	938.2
Soyabean meal (48%)	140.0	130.0	Nil	Nil	Nil	85.0	80.0	Nil	Nil	Nil
Animal fat	30.0	30.0	34.0	34.0	34.0	31.0	31.0	37.0	37.0	37.0
Calcium carbonate	10.0	11.0	10.5	10.5	10.5	10.0	10.0	10.0	10.0	10.0
Monocal. phos.(18Ca21P)	5.5	5.5	6.5	6.5	6.5	4.0	4.0	4.5	4.5	4.5
Iodized salt	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Vit-Trace min. premix[y]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
L-Lysine Hcl (78%)	Nil	3.0	7.4	7.4	7.4	Nil	2.0	4.8	4.8	4.8
L-Threonine (98%)	Nil	1.5	3.5	Nil	Nil	Nil	1.0	2.2	Nil	Nil
DL-Methionine	Nil	0.5	1.3	1.3	Nil	Nil	0.2	0.7	0.7	Nil
L-Tryptophan	Nil	Nil	0.6	Nil	Nil	Nil	Nil	0.3	Nil	Nil
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Nutrient levels (Dry matter basis):										
Energy (MJ kg^{-1} DE)	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Crude protein (g kg^{-1})	177.8	177.8	133.3	133.3	133.3	155.5	155.5	127.8	127.8	127.8
Crude Fibre (g kg^{-1})	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Crude fat (g kg^{-1})	5.2	5.2	5.8	5.8	5.8	5.4	5.4	6.1	6.1	6.1
Calcium (g kg^{-1})	7.2	7.2	7.2	7.2	7.2	6.7	6.7	6.7	6.7	6.7
Phosphorus (g kg^{-1})	6.1	6.1	6.1	6.1	6.1	5.5	5.5	5.5	5.5	5.5

[z] Diet 1 = Covered-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

[y] Supplied per kilogram of diet: vitamin A, 8,400 IU; vitamin D3, 840 IU, vitamin E, 30 IU; vitamin K, 2.5 mg; vitamin B_{12}, 18 mcg; riboflavin, 3.6 mg; niacin, 19.8 mg; D-pantothenic acid, 9.7 mg; choline 115 mg; iron, 84 mg; zinc, 150 mg; manganese, 24 mg; copper, 120 mg; iodine, 0.3 mg and selenium, 0.36 mg.

Table 3. Amino-acid composition of experimental Grower and Finisher diets in experiment1 (Hulless-barley)

	Grower					Finisher				
Diets[z]:	1	2	3	4	5	1	2	3	4	5
Amino acids (g kg^{-1}):										
Arginine	8.8	9.0	6.4	5.7	5.7	7.9	7.2	6.7	6.5	6.8
Lysine	7.3	10.9	10.9	11.1	10.9	6.0	8.2	9.1	9.0	9.0
Threonine	6.1	8.3	7.9	4.1	3.8	5.4	6.7	7.3	5.1	5.0
Methionine	3.4	3.5	4.1	4.1	3.2	3.3	3.4	3.7	3.7	3.3
Cystine	2.2	2.1	2.0	1.7	1.7	2.5	2.3	2.3	1.9	2.0
Tryptophan[y]	1.9	1.8	1.8	1.4	1.4	1.6	1.5	1.5	1.4	1.4
Histidine	3.9	4.0	3.1	2.7	2.7	3.7	3.2	3.2	3.2	3.3
Leucine	12.7	12.5	10.0	9.2	9.2	12.0	10.9	10.9	10.7	11.1
Isoleucine	6.0	6.2	5.1	4.8	4.7	6.2	5.3	5.5	5.2	5.3
Phenyl alanine	8.9	9.2	7.4	6.7	6.1	8.7	7.4	7.9	7.8	8.0
Tyrosine	4.9	5.2	4.0	3.5	3.4	4.7	4.0	4.3	4.1	4.2
Valine	8.0	8.2	6.9	6.3	6.3	7.8	6.9	7.8	7.8	7.8
Aspartic	13.0	12.4	8.4	7.7	7.7	10.5	9.8	8.8	8.7	9.0
Glutamic	43.3	43.1	38.0	33.1	31.1	43.4	41.4	42.0	42.3	43.3
Proline	20.9	18.7	17.9	13.9	12.5	18.4	17.8	19.3	18.0	19.2
Glycine	7.0	6.8	5.4	5.1	5.0	6.3	5.8	5.8	5.8	6.0
Alanine	7.1	7.0	5.8	5.3	5.2	6.5	6.1	6.0	5.8	6.1
Amino acid ratios:										
Thre.: Lysine	0.83	0.76	0.72	0.37	0.35	0.90	0.82	0.80	0.57	0.55
Meth.: Lysine	0.46	0.32	0.37	0.37	0.29	0.55	0.41	0.41	0.41	0.37
Tryp.: Lysine	0.26	0.16	0.16	0.13	0.13	0.27	0.18	0.16	0.15	0.15

[z] Diet 1 = Hulless-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

[y] Tryptophan value was calculated not analysed

The amino acid analyses were conducted at the Department of Animal Science, University of Manitoba, Winnipeg, MB.

Table 4. Amino acid composition of experimental Grower and Finisher diets in experiment2 (Covered-barley)

	Grower					Finisher				
Diets[z]:	1	2	3	4	5	1	2	3	4	5
Amino acids (g kg^{-1})										
Arginine	9.1	9.1	4.5	4.2	4.2	9.1	7.9	4.4	4.4	4.4
Lysine	7.9	10.8	10.1	10.5	10.5	6.0	8.7	8.4	8.7	8.5
Threonine	6.0	7.6	6.6	5.0	3.3	4.1	5.6	5.8	3.2	3.4
Methionine	3.2	3.3	3.6	3.9	2.4	2.3	2.7	3.2	3.4	2.4
Cystine	2.1	1.8	1.9	1.3	1.2	1.5	1.5	1.7	1.5	1.4
Tryptophan[y]	2.0	1.9	1.8	1.1	1.1	1.7	1.6	1.5	1.1	1.1
Histidine	3.9	3.8	2.2	2.2	2.2	3.1	3.3	2.2	2.2	2.2
Leucine	12.4	11.7	7.1	7.7	7.2	9.8	10.4	7.3	7.3	7.2
Isoleucine	6.0	5.3	3.2	3.5	3.2	3.5	4.2	2.4	2.3	2.5
Phenyl alanine	8.4	8.1	4.9	5.2	5.0	6.9	7.3	5.2	4.8	4.9
Tyrosine	4.8	4.7	2.4	2.8	2.7	3.5	4.2	2.4	2.3	2.5
Valine	7.3	7.0	4.8	4.9	4.7	6.0	6.4	4.8	4.9	5.1
Aspartic	14.7	14.4	6.4	6.8	6.4	12.4	12.1	10.9	10.4	10.0
Glutamic	37.1	36.5	24.3	26.0	23.4	31.5	31.9	24.7	22.7	23.3
Proline	13.7	13.8	11.0	13.3	9.5	12.4	12.1	10.9	10.4	10.0
Glycine	7.0	6.8	4.3	4.7	4.5	5.7	6.1	4.1	4.1	4.1
Alanine	7.4	7.1	4.3	4.7	4.5	6.1	6.3	4.7	4.2	4.4
Amino acid ratios:										
Thre.: Lysine	0.76	0.70	0.65	0.48	0.31	0.68	0.64	0.69	0.37	0.40
Meth.: Lysine	0.40	0.30	0.35	0.37	0.23	0.38	0.31	0.38	0.39	0.28
Tryp.: Lysine	0.25	0.17	0.18	0.10	0.10	0.28	0.18	0.18	0.13	0.13

[z] Diet 1 = Covered-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

[y] Tryptophan value was calculated not analysed

The amino acid analyses were conducted at the Department of Animal Science, University of Manitoba, Winnipeg, MB.

Table 5. Effect of feeding hulless-barley diets with soybean meal replaced by different combinations of amino acids, lysine, threonine, methionine, and tryptophan to reduce N excretion in manure on growth performance and carcass quality (experiment 1)

	Diet[z]					Sex-type		Pooled	P values		
	1	2	3	4	5	Barrows	Gilts	SEM	Diet	Sex	D x S
No. of pigs	32	32	32	32	32	80	80				
Live weight (kg):											
Initial	20.9	21.0	21.1	20.8	20.9	20.4	21.5	0.12	0.093	0.001	0.899
Final	104.3	105.2	104.8	104.5	104.3	104.6	104.6	0.44	0.756	0.310	0.452
Ave. Daily weight gain (kg):											
Grower	0.84	0.95	0.91	0.76	0.76	0.86	0.83	0.01	0.075	0.107	0.433
Finisher	0.99	1.06	1.05	1.13	1.13	1.12	1.02	0.01	0.355	0.023	0.385
Overall	0.91	1.01	0.98	0.93	0.93	0.97	0.93	0.01	0.648	0.029	0.449
Gain to Feed ratio :											
Grower	0.462a	0.516b	0.505b	0.437c	0.432c	0.474	0.468	0.003	0.001	0.278	0.764
Finisher	0.341a	0.373abd	0.379bd	0.419c	0.395cd	0.382	0.381	0.006	0.004	0.907	0.397
Overall	0.389ac	0.429b	0.428b	0.426b	0.412bc	0.417	0.416	0.004	0.008	0.888	0.504
Ave. Daily feed intake (kg DM):											
Grower	1.63	1.66	1.63	1.57	1.58	1.63	1.60	0.016	0.201	0.411	0.514
Finisher	2.59	2.56	2.46	2.46	2.55	2.63	2.41	0.035	0.580	0.002	0.808
Carcass quality[y]:											
Backfat(mm)	15.1	13.8	14.4	15.1	14.5	15.2	13.9	0.20	0.592	0.941	0.297
Carcass Index	107.7	107.8	109.5	106.7	107.3	107.5	108.1	0.32	0.029	0.369	0.408
Yield (%)	79.2	79.9	80.1	79.8	79.7	79.5	80.0	0.14	0.303	0.443	0.657
Plasma urea nitrogen (mg dL^{-1})[x]:	19.8a	16.6b	15.3bc	15.8bc	14.6c	17.4	15.4	0.28	0.001	0.001	0.067

[z] Diet 1 = Hulless-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

[y] Back-fat = Back-fat measurement at P2 site adjusted to 100 Kg live weight; Yield % = weight of warm carcass (after removal of organs and digestive tract) as % of final live weight.

[x] Plasma urea nitrogen values in each diet contained 12 observations.

Least square means followed by different letters are significantly different ($P < 0.05$)

Table 6. Effect of feeding hulless-barley diets with soybean meal replaced by different combinations of amino acids, lysine, threonine, methionine, and tryptophan to reduce N excretion in manure on apparent absorption and retention of nutrients in gilts (experiment 1)

	Diets[a]					Pooled	p value
	1	2	3	4	5	SEM	Diet
Grower period:							
No of gilts	4	4	4	4	4		
Dry matter:							
Intake (g d^{-1})	1727.1a	1761.9a	1521.9b	1731.3a	1808.2a	25.79	0.031
Absorption (%)	87.6	87.9	85.8	86.3	87.9	0.34	0.208
Retention (%)	83.1	83.8	82.5	83.5	85.0	0.41	0.402
Energy:							
Intake (MJ d^{-1})	30.4	31.3a	26.9b	30.4a	31.6a	0.46	0.038
Absorption (%)	87.4	88.2	85.8	86.0	87.6	0.24	0.188
Retention (%)	84.6	85.8	8395	84.5	85.9	0.38	0.423
Nitrogen:							
Intake (g d^{-1})	47.8a	50.7a	36.4b	37.0b	38.2b	0.63	0.001
Absorption (%)	84.0ab	86.2a	80.9b	80.6b	81.2b	0.54	0.024
Retention (%)	43.1a	55.9b	58.8b	58.8b	58.9b	1.10	0.002
Excretion in:							
Faeces (g d^{-1})	7.6	7.1	6.9	7.1	7.2	0.24	0.886
Urine (g d^{-1})	19.5a	15.4b	8.1c	8.2c	8.5c	0.48	0.001
Total (g d^{-1})	27.1a	22.5b	14.9c	15.3c	15.7c	0.57	0.001
Reduction (%)		17.0	33.8	32.0	30.2		
Finisher period:							
No of gilts	4	4	4	4	4		
Dry matter:							
Intake (g d^{-1})	2559.1	2742.2	2540.3	2551.9	2719.9	54.33	0.630
Absorption (%)	88.4	88.1	87.7	85.6	86.7	0.41	0.230
Retention (%)	82.9	83.2	82.9	81.1	82.0	0.38	0.464
Energy:							
Intake (MJ d^{-1})	45.1	48.5	45.1	45.2	47.7	0.96	0.678
Absorption (%)	88.6	88.2	87.8	86.2	86.7	0.43	0.541
Retention (%)	85.1	85.2	84.8	83.3	83.7	0.41	0.541
Nitrogen:							
Intake (g d^{-1})	70.3	73.2	64.4	63.7	70.2	1.39	0.195
Absorption (%)	88.7	87.8	86.1	86.0	86.2	0.73	0.710
Retention (%)	36.2	39.9	34.6	37.3	39.0	1.21	0.652
Excretion in:							
Faeces (g d^{-1})	7.8	8.9	8.9	8.7	9.6	0.44	0.806
Urine (g d^{-1})	36.9	35.0	33.1	30.9	33.2	1.07	0.501
Total (g d^{-1})	44.7	43.9	42.0	39.6	42.9	1.01	0.562
Reduction (%)		1.8	4.3	9.8	2.3		

[a] Diet 1 = Hulless-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

Least square means followed by different letters are significantly different ($p < 0.05$).

Table 7. Effect of feeding covered-barley diets with soybean meal replaced by different combinations of amino acids, lysine, threonine, methionine, and tryptophan to reduce N excretion in manure on growth performance and carcass quality (experiment 2)

	Diets					Sex-type		Pooled	P values		
	1	2	3	4	5	Barrows	Gilts	SEM	Diet	Sex	D x S
No. of pigs	32	32	32	32	32	80	80				
Live weight (kg):											
Initial	20.2	20.1	20.2	20.2	20.5	20.2	20.3	0.06	0.967	0.766	0.751
Final	104.5	105.0	103.6	101.6	100.0	103.0	102.9	0.32	0.0540234		0.850
Ave. Daily weight gain (kg):											
Grower	0.83a	0.96b	0.75c	0.57d	0.55d	0.75	0.72	0.009	0.001	0.424	0.281
Finisher	1.07a	1.18b	1.03a	0.84c	0.81c	1.04	0.93	0.013	0.002	0.039	0.828
Overall	0.94a	1.06b	0.87c	0.68d	0.65d	0.87	0.81	0.008	0.001	0.087	0.483
Gain to Feed ratio :											
Grower	0.417a	0.516b	0.434a	0.286c	0.302c	0.399	0.384	0.008	0.001	0.361	0.843
Finisher	0.374a	0.394a	0.386a	0.320b	0.298b	0.356	0.353	0.004	0.001	0.613	0.297
Overall	0.393a	0.444bb	0.407a	0.300b	0.298b	0.372	0.365	0.005	0.001	0.414	0.687
Ave. Daily feed intake (kg DM):											
Grower	1.82	1.67	1.86	1.86	1.66	1.72	1.71	0.041	0.072	0.978	0.162
Finisher	2.51ab	2.65a	2.38ab	2.28b	2.28b	2.51	2.33	0.046	0.040	0.039	0.966
Carcass quality[y]:											
Backfat(mm)	14.7	13.7	16.0	15.4	16.0	15.6	14.6	0.23	0.653	0.857	0.612
Carcass Index	106.3	107.8	105.9	106.1	105.8	106.3	106.4	0.29	0.097	0.654	0.916
Yield (%)	78.4	78.7	78.9	79.0	78.8	78.7	78.8	0.12	0.563	0.322	0.395
Plasma urea nitrogen (mg dL^{-1})[x]:	14.3a	11.6b	6.5c	9.5d	11.2b	11.3	10.0	0.20	0.001	0.759	0.168

[z] Diet 1 = Covered-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

[y] Back-fat = Back-fat measurement at P2 site adjusted to 100 Kg live weight; Yield % = weight of warm carcass (after removal of organs and digestive tract) as % of final live weight.

[x] Plasma urea nitrogen values in each diet contained 16 observations

Least square means followed by different letters are significantly different ($P < 0.05$)

Table 8. Effect of feeding covered-barley diets with soybean meal replaced by different combinations of amino acids, lysine, threonine, methionine, and tryptophan to reduce N excretion in manure on apparent absorption and retention of nutrients in gilts (experiment 2)

	Diets[z]					Pooled	p value
	1	2	3	4	5	SEM	Diet
Grower period:							
No of gilts	4	4	4	4	4		
Dry matter:							
Intake (g d^{-1})	1581.6	1484.0	1582.0	1605.4	1651.2	43.62	0.882
Absorption (%)	82.3	82.3	80.5	79.8	80.1	0.31	0.103
Retention (%)	79.0	79.2	78.4	77.1	77.5	0.36	0.450
Energy:							
Intake (MJ d^{-1})	30.3	28.4	30.3	30.9	32.0	0.84	0.835
Absorption (%)	82.9	82.8	81.1	80.5	80.9	0.31	0.137
Retention (%)	81.0	81.1	80.1	79.2	79.5	0.33	0.412
Nitrogen:							
Intake (g d^{-1})	43.0a	39.7a	29.6b	30.3b	31.3b	0.97	0.002
Absorption (%)	82.0a	82.1a	77.3b	76.4b	74.9b	0.50	0.026
Retention (%)	57.0a	63.4ab	66.9b	56.9a	56.1a	1.09	0.043
Excretion in:							
Faeces (g d^{-1})	7.7	7.0	6.7	7.0	7.6	0.29	0.776
Urine (g d^{-1})	10.8a	7.6b	2.9c	6.1b	6.0b	0.39	0.001
Total (g d^{-1})	18.5a	14.7ab	9.6c	13.1bc	13.6bc	0.59	0.001
Reduction (%)		20.5	34.7	10.9	7.5		
Finisher period:							
No of gilts	4	4	4	4	4		
Dry matter:							
Intake (g d^{-1})	2329.3	1824.5	1979.3	2979.1	2522.2	6818	0.134
Absorption (%)	84.2a	79.2b	82.7ab	82.2ab	79.7ab	0.50	0.035
Retention (%)	79.7a	74.0b	79.4ab	79.1ab	73.8ab	0.62	0.013
Energy:							
Intake (MJ d^{-1})	45.3	38.7	40.1	57.1	51.2	0.88	0.063
Absorption (%)	85.3a	81.6b	85.6a	83.3ab	81.7b	0.85	0.030
Retention (%)	82.9a	79.0b	83.8a	81.6ab	78.8b	0.44	0.008
Nitrogen:							
Intake (g d^{-1})	54.4a	45.1a	36.9b	56.8a	46.8a	1.44	0.009
Absorption (%)	87.1a	81.4b	82.8a	81.0b	78.1b	0.60	0.015
Retention (%)	44.5	25.3	53.7	64.4	53.0	2.30	0.109
Excretion in:							
Faeces (g d^{-1})	6.9a	8.5ab	6.5a	10.2b	9.6b	0.29	0.036
Urine (g d^{-1})	22.7a	24.6a	10.2b	12.7b	12.8b	0.65	0.001
Total (g d^{-1})	29.6a	33.2a	16.7b	22.9ab	22.4ab	0.69	0.001
Reduction (%)		Nil	49.7	31.0	32.5		

[z] Diet 1 = Covered-barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

Least square means followed by different letters are significantly different ($p < 0.05$).

Table 9. Effect of feeding hulless or covered barley diets with soybean meal replaced by different combinations of amino acids, lysine, threonine, methionine, and tryptophan to reduce N excretion in manure on ammonia concentration in overhead space of manure containers during the finisher period in gilts

	Diet[z]					Pooled	p value
	1	2	3	4	5	SEM	Diet
Experiment 1 (Hulless-barley):							
No of gilts	4	4	4	4	4		
Ammonia (ppm)	207.7a	198.0a	172.5ab	137.5b	212.7a	7.82	0.048
Experiment 2 (Covered-barley):							
No of gilts	4	4	4	4	4		
Ammonia (ppm)	144.5a	266.0b	41.0c	21.0d	21.0d	9.82	0.003

[z] Diet 1 = Hulless or covered barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.

Least square means followed by different letters are significantly different ($p < 0.05$).

Table 10. Economic evaluation of replacing soybean meal with supplemental amino acids in hulless and Covered barley diets to reduce nitrogen excretion in swine manure..

	Diet [a]				
	1	2	3	4	5
Experiment 1 (Hulless-barley)					
Cost of amino acids per pig ($):					
Lysine ($5.00/kg)	--	3.90	5.52	5.69	5.83
Threonine ($10.00/kg)	–	3.33	5.17	–	--
Methionine ($5.00/kg)	–	0.31	0.57	0.61	--
Tryptophan ($40.00/kg)	–	–	1.72	–	–
Total amino acid cost	–	7.54	12.98	6.30	5.83
Cost of soybean meal ($300/t)	4.03	2.86	–	–	–
Extra cost over grain	4.03	10.40	12.98	6.30	5.83
Improved ADG ($0.50/day)	–	4.10	3.10	0.80	0.95
Improved carcass value ($1.30/kg)	–	0.12	2.00	-1.10	-0.44
Net extra cost	–	6.18	7.88	6.60	5.22
Manure N reduction compared to diet 1 (%):					
Grower period	–	17.0	45.0	43.5	42.1
Finisher period	–	1.8	6.0	11.4	4.0
Experiment 2 (Covered barley)					
Cost of amino acids per pig ($):					
Lysine ($5.00/kg)	–	2.59	6.16	8.48	8.19
Threonine ($10.00/kg)	–	2.59	5.74	–	--
Methionine ($5.00/kg)	–	0.35	0.99	1.39	--
Tryptophan ($40.00/kg)	–	–	3.56	–	--
Total amino acid cost	–	5.53	21.98	9.87	8.19
Cost of soybean meal ($300/t)	7.06	5.70	–	–	--
Extra cost over grain	7.06	11.23	21.98	9.87	8.19
Improved ADG ($0.50/day)	–	4.90	-2.95	-14.90	-15.85
Improved carcass value ($1.30/kg)	–	1.66	-0.46	-0.22	-.55
Net extra cost	–	4.67	25.39	24.99	24.59
Manure N reduction compared to diet 1 (%):					
Grower period	–	20.5	48.1	29.2	26.5
Finisher period	–	Nil	43.6	22.6	24.3

[a] Diet 1 = Hulless or covered barley control; 2 = same as diet 1 + amino acids lysine, threonine, and methionine according to NAS-NRC (1998); 3 = same as diet 2 except the soybean meal was replaced by amino acids lysine, threonine, methionine and tryptophan; 4 = same as diet 3 except threonine and tryptophan were omitted; 5 = same as diet 3 except threonine, methionine and tryptophan were omitted.